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Substructure hardening in duplex low density steel

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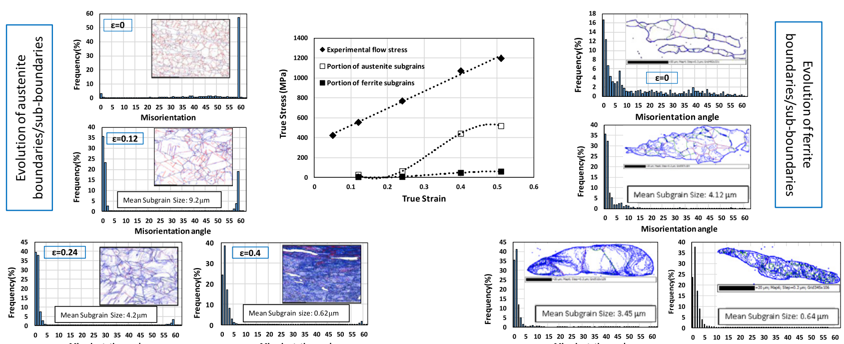
HIGHLIGHTS

- Significant strain hardening capability of low density steel due to substructure development
- Nano-size partitioning of the austenite (~530 nm) and ferrite (~500 nm) grains
- Progressive deviation of twin boundaries from Σ3-coincidence due to substructure development
- Substructure refinement possesses a high portion of the measured flow stress

GRAPHICAL ABSTRACT



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ABSTRACT

The present work was conducted to evaluate the effects of substructure development on the strain hardening behavior of Fe–17.5Mn–8.3Al–0.74C–0.14Si lightweight steel. This was performed applying tensile testing method at ambient temperature. The significant strain hardening capability of the experimental steel is attributed to the cell structure formation and its progressive evolution to subgrains over a wide range of applied strain. The continuous subgrain refinement with the applied strain could lead to the nano-size partitioning of the austenite (~530 nm) and ferrite (~500 nm) grains. The size of substructure (mesh length) appears to be stabilized at true strains above 0.35, thereby reducing the rate of work hardening and inducing subgrain rotation to higher misorientations. The contribution of substructure refinement is significant and possesses a high portion of the measured flow stress (~550 MPa for austenite and ~70 MPa for ferrite at the true strain of 0.5).

1. Introduction

Several mechanisms are proposed to justify the observed continuous strain hardening and excellent combination of strength/ductility (over 50,000 MPa.%) in low density steels [1–3]. Twinning induced plasticity and/or transformation induced plasticity effects are expected to somewhat disappear in lightweight steels due to their higher aluminum content [4]. In fact, the stacking fault energy is sufficiently high to suppress or delay twin formation or martensitic transformation. Accordingly, the work hardening phenomena in austenitic low density steels may be attributed to the intensified dislocation interactions. This speculation is challenged considering some report concerning the occurrence of γ/α' transformation in duplex aluminum-bearing structures [5–10] where the retained austenite characteristics define its stability and may locally trigger the tripping effect. This finding has been well

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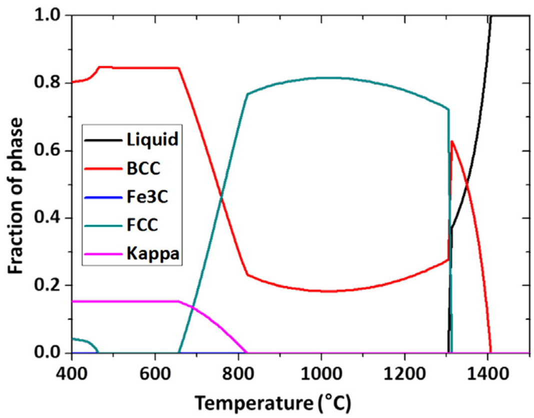

Fig. 1. The equilibrium phase fraction of the experimental lightweight steel calculated by Thermo-Calc.

followed and discussed by Seok Su Sohn et al. [4,11]. They believe that the level of stacking fault energy is not the main parameter determining the austenite deformation mechanisms. The austenite grain size, its preferred crystallographic orientation and its morphology may also act as influencing factors. The simultaneous operation of multi-deformation mechanisms, i.e. martensitic transformation and twinning, in these cases is attributed to the optimal mechanical stability of austenite. Yoo et al. [12,13], Park et al. [14] and Gutierrez-Urrutia et al. [15] also relate the corresponding strengthening mechanisms, which account for the excellent strength-ductility combination of low density steels, to the substructures associated with planar glide such as Taylor lattice, Taylor lattice domain boundaries and crystallographic microbands. To this end, the glide plane softening in association with the occurrence of short range ordering is considered as the main cause of planar glide. They also believe that the short range ordering would relate to the formation of C-Mn octahedral clusters or originate from the presence of shearable nano-sized κ-carbides.

As is understood, the available literature present a complex picture of the strain accommodation in austenitic low density steels. This complexity may be increased due to the constraint coming from the presence of δ ferrite along with the presence of nano-sized κ-precipitate in duplex or triplex structures. In addition it is theoretically speculated that besides the aforementioned mechanisms responsible for strain hardening capability of lightweight steels, the substructure formation and refinement associated with wavy dislocation configuration (cells, cell blocks or subgrains) may also be involved. This concept has been assessed in the case of conventional twinning induced plasticity steels with medium stacking fault energy [16,17]. It was found that the early hardening stage was accompanied with planar (Taylor lattices) and wavy (cells, cell blocks) dislocation configuration, the transition of which would be dictated by the chemical composition and the amount of imposed strain. Concurrently, competing deformation mechanisms, namely twinning and microbanding were found to contribute in continuous strain hardening behavior of the investigated steels. The present authors believe that the degree of substructure development associated with cell and subgrain formation might be intensified in the case of low density steels with relatively higher stacking fault energies (>60 mJ/m^2). In fact, the maximum potential and individual strengthening contribution of such mechanism is still unclear. The aforementioned capability is assessed and well explored in the present work through elaborating a free κ precipitate duplex ($\alpha + \gamma$) microstructure,

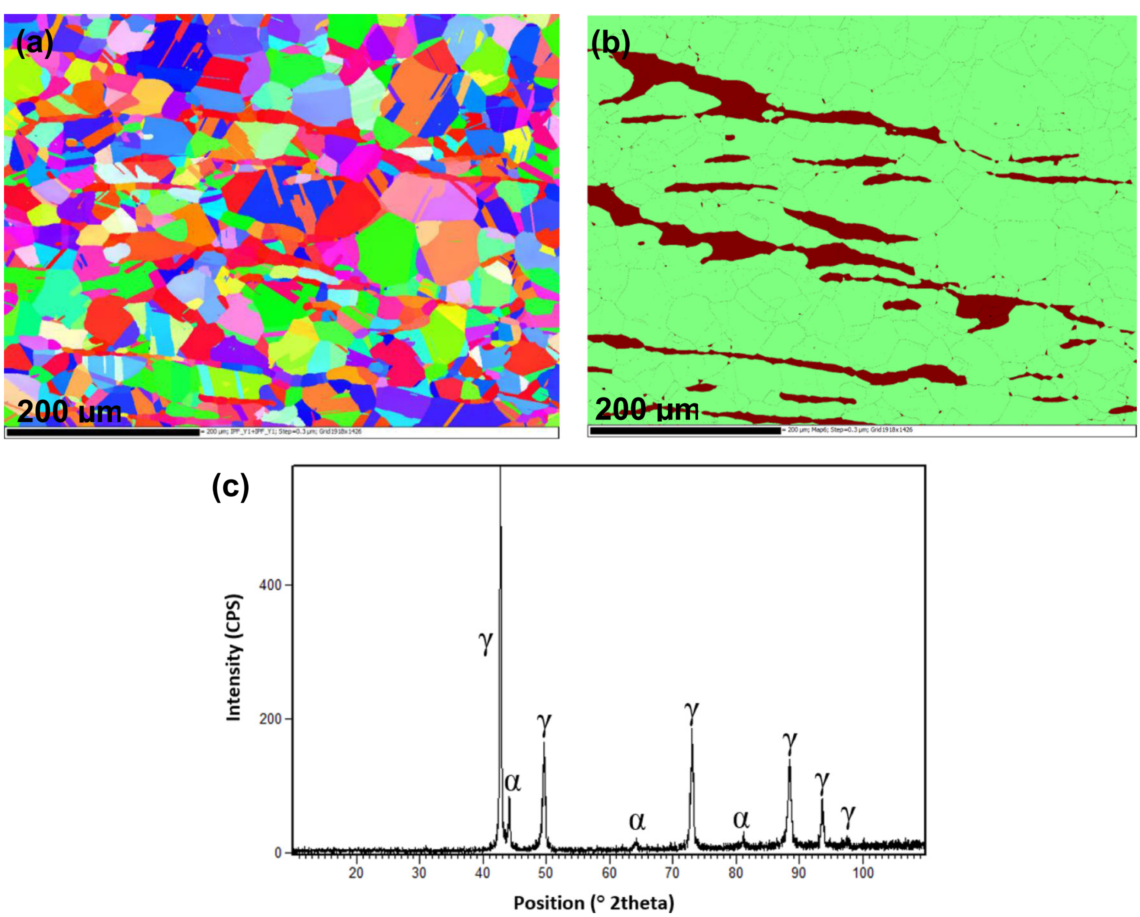

Fig. 2. The inverse pole figure (a), phase map (b) and X-ray diffraction pattern (c), of the initial microstructure containing ~10% ferrite phase. In (b) the red phase indicates ferrite. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)